MODELING OF HIGH ALUMINA BLAST FURNACE SLAG

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Technology

in

Steel Technology

By

INDRADEV VERMA

Roll No. 213MM2490

Department of Metallurgy & Material Engineering

National Institute of Technology Rourkela

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Certificate

This is to certify that the thesis entitled, "**Modeling of high alumina blast furnace slag**" submitted by Mr. **Indradev Verma** in partial fulfillment of the requirements for the award of Master of Technology Degree in Metallurgy & Material Engineering with specialization in "**Steel Technology**" during session 2013-15 at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.This work has not been submitted at other University/ Institute for the award of any degree or diploma.

Date:

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Abstract

Indian blast furnaces are running of high alumina slag due to high alumina to silica ratio in ores. slag mainly contains lime(CaO), silica (SiO_2),alumina(Al_2O_3) and magnesia(MgO) along with smalleramount of FeO, MnO, TiO_2, K_2O and S. The flow characteristics of the slag determine size, shape and area of the cohesive zone in the furnace. The cohesive zone in the furnace acts as a gas distributor and its area let down the furnace diminishes the high temperature zone in the furnace, which moves the lime dissemination circle to lower levels.In the present work, softening and melting test were conducted for CaO-SiO_2-MgO-Al_2O_3 quaternary slag system, to determine theflow characterstics of synthetic slag using a Leitz high temperature microscope as per German standard 51730. Empirical equations are developed to predict softening temperature (ST), hemispherical temperature (HT) and flow temperature (FT).Slag viscosity was also determinedusing Iida modelwrt C/S ratio, MgO and temperature ranging from 1623K and 1823K which covers the liquidus temperature.viscosity decreases with increase of MgO content, an increase of temperature having a diminishing effect on decreasing of viscosity at higher MgO content. Increase in C/S ratio decreases viscosity because CaO acts as network modifier.

Keywords:- Cohesive zone ,basicity ratio, liquidus & melting temperature, viscosity, Iida model.

Chapter-1

Introduction

1.1 Introduction

The iron making (BF) is the most significant chemical reactor operating in counter-current heat exchanger principle for producing molten iron required for lion share of world's primary steel. The smooth operation of and quality of produced hot metal are significantly dependent on the formation and mineralogical transformations of slag during descend of burden inside the furnace . The melting zone of slag determines shape, size and behaviour of cohesive zone of the furnace . So, fluidity and melting characteristics of slag evidently play a major role in determining the productivity. It is observed that a high softening temperature coupled with a relatively low flow temperature increases the probability of narrow cohesive zone formation at relatively lower part of the furnace [1].This results reduction in the distance travelled by the liquid slag in the furnace and consequently decreases Silicon pick- up [2, 3].As the slag trickles down, it assimilates silica and alumina of ash, generated from combustion of coke. The process of trickling down depends on viscosity of slag, which further is governed by the composition and temperature of the melt.Viscosity is also a function of temperature of melt [4].In writing, representations of the liquidus temperature have been done utilizing distinctive classifications. Osborn [5] and Snow [6] have characterized liquidus temperature as the temperature at which the first precious stone structures amid chilling off the melt. Then again, Ohno et al. [7] have reported that liquidus temperature is the temperature at which the last precious stone vanishes amid warming. The combination conduct of a slag relies on upon its synthetic piece. Different analysts have embraced different routines for figuring/forecast of the liquidus temperature of a slag. Liquidus temperatures are figured graphically utilizing technique for Lesathala. [8] Fine and Arac [9] have created techniques for figuring out discouragement/height of liquidus temperature of manufactured blast furnaceslag as an element of minor constituents (MnO, TiO_2, FeO, and Na_2O) in the slag. Datta et al. [10] haverecommended a measurable technique for foreseeing the liquidus temperature of semisynthetic blast furnaceslag as a component of C/S proportion at diverse Al_2O_3, MgO, and TiO_2 levels. Quadratic relapse mathematical statements have been produced by Eric et al. [11] to anticipate liquidus temperature of ferromanganese slag utilizing SAS bundle. Utilizing the technique for factorial configuration, experimental comparisons have been produced to foresee the ST, HT, and FT by all the while changing Al_2O_3/CaO proportion, MgO content. Combination conduct of slag is by and large depicted as far as four trademark temperatures [12], for example, starting deformity temperature (IDT), symbolizing surface stickiness, vital for development of the material in the strong state; softening temperature (ST), symbolizing plastic contortion, demonstrating begin of plastic twisting; hemispherical temperature (HT), which speaks to the liquidus temperature of the slag Implying its drowsy flow; assuming a critical part in the aeromechanics of the furnace and warmth and mass exchange; and flow temperature (FT), symbolizing the fluid versatility [13].The flow normal for blast furnaceslag is emphatically blasted by the degree of decrease of iron oxide at low temperature (in the granular zone) other than being affected by the structure, and the quality and the amount of the gangue in the iron bearing materials. Roy et al. [14] have demonstrated that the CaO/SiO_2 and MgO substance of the blast furnaceslag significantly blast its softening-dissolving properties. However a few studies on flow attributes of diverse blast furnaceslag have been accounted for in writing, a centered examination on the blast of CaO/SiO_2 proportion, MgO and Al_2O_3 content on flow qualities of blast furnaceslag yet to be performed.In the present work,using multi- straight relapse examination, exact mathematical statements have been created to foresee the ST, HT, and FT regarding CaO/SiO_2 proportion, MgO and Al_2O_3 content. The figured estimations of the trademark temperatures utilizing the observational mathematical statements are contrasted and tentatively decided qualities for a few blast furnaceslag to check the legitimacy of the comparisons created.

Viscosity of liquid slag changes in wide range relying upon temperature and piece. A few of elements in anblast furnaceprocedure, for example, the rate of different responses and the liquid flows, are influenced by the properties of liquid slag. Among them, it is no doubt understood that the viscosity is an essential physical property for comprehension the system structure of slag melts and for reenacting the rate of different phenomena in high-temperature metallurgical procedures. Physicochemical assets of slag, such as viscosity, are important practice variables of the blast furnace process, and of importance when reviewing the process and relating the knowledge in controlling and optimization. Slag viscosity is a transportation property that communicates to the response kinetics and the degree of reduction of the final slag**1**. Slag viscosity also concludes the slag–metal partingproficiency, and consequently the metal yield and impurity eliminationcapability. In process, the slag viscosity is revealing of the easiness with which slag could be tapped from the furnace, and therefore transmits to the vitality obligation and productivity of the process.The capability to forecast the slag viscosity and liquidus temperature has the possible to optimize the investigation and decision-making control of blast furnaces, substituting the use of rules of thumb concerning to slag configurations. Efforts have been made in the past to measure and model viscosities for different slag systems, of which the outcomes of many can be found in printed literature**1,2**. Some of these models relate the effect of the different constituents very well, 310 but often do not deliberate the effect of the accustomed liquid slag composition, and precipitation of solids at lower temperatures. In the typical slag system of interest, an increase in basicity not only indications to a lower liquid viscosity due to damaged silicate links, but also increases the possibility of solids precipitation, thus increasing the viscosity. Phase equilibrium controls are used to primarilydefine the liquidus temperature, and then to estimation the amount (if any) of precipitated solids. For multiphase slag, the projected amount of solids is to be used to correct the viscosity expected by the liquid viscosity model. To augment the process using the established model, the first step would be to put on the models to ancient data to create a presentation baseline and regulateobjectives for improvement. In this work, the objective was to develop liquidus temperature and actual-viscosity models and submissionpractices, to demonstrate how they could be used for a blast furnace, to monitor presentation and motivation optimization. Slag viscosity was moreoverobvious utilizing iida model with as a part of the temperature range somewhere around 1623 and 1823K which covers the liquidus temperature ,in light of the fact that the viscosity at this temperature will change greatly.The effect of CaO/SiO_2, MgO and temperature on viscosity were studied.The results demonstrate that the viscosity diminishes with increment in basicity and MgO content.

Chapter -2

Literature Survey

2.1 Introduction to slag

Indian blast furnace work in a high alumina slag running described by high alumina, attributable to wide measure of alumina data through the iron-bearing weight and powder of the coke. The alumina include in Tata Steels furnaces is around 75kg/thm and resultant alumina in slag in the middle of 20and 22 percent relying on the slag rate of 320-360kg/thm.High alumina slag have high-softening focuses and high viscosities. Along these lines, to keep up satisfactory smoothness in the slag, a high level of superheat is to be kept up in the hearth bringing about high silicon hot metal, high coke rate and lower efficiency. Keeping in mind the end goal to enhance the execution lists of blast furnace, one of the imperative measures is to flowline the slag attributes regarding its liquefying qualities and ease, at the same guaranteeing that the slag has a satisfactory desulphurization and salt evacuation limit.

In blast furnace, arrangement of slag and the mineralogical change that the slag experiences amid plunge of weight inside the furnace, blast the nature of hot metal. It is realized that the parts of slag to be specific silica and alumina expand the viscosity while the vicinity of calcium oxide decreases the viscosity. The dissolving zone of slag decides the strong zone of blast furnace and consequently the ease and liquefying attributes of slag assume a significant part in deciding the blast furnace efficiency. At first iron rich slag is shaped and from that point because of digestion of CaO and MgO from flux, the piece of slag fluctuates. As the slag flows down, it acclimatizes silica and alumina of powder, produced from ignition of coke. The procedure of flowing down relies on upon viscosity of slag, which further is administered by the creation and temperature of the melt. The BF slag can not be of any particular science. Its structure on the science of the weight, coke rate, fuel infusion and temperature of the furnaceoperation . The charge contains alumina, silica, mangnesia and lime as the fundamental constitutes . The minor oxides may be Cr_2O_3, TiO_2, FeO and so on.

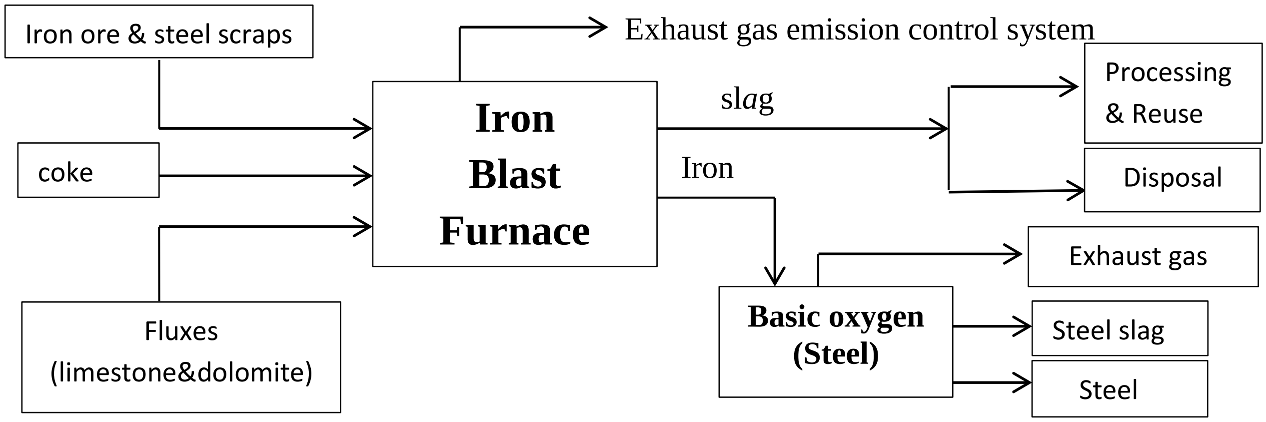


Fig. 2.1 Schematic diagram represents the operation and slag production.

2.1.1 Basic Requirement of Slag for Normal Operation of a furnace

For smooth operation of a furnace, the must satisfy the following requirements:

a) The slag volume should be kept as low as possible keeping in view alkali removal and desulphurization requirements.
b) The primary slag must be confined in composition.
c) Slag formation should be confined to a limited height of and the slag should be stable.
d) The slag must be just enough to get sufficiently heated and should provide good permeability in the zone of slag formation.
e) The melting point of the slag should be neither too high nor too low.

The softening purpose of the slag chooses the temperature of the slag at the tuyere level. On the off chance that the slag is low melting point, such a corrosive slag, it softens at a nearly larger amount in the furnace and in the wake of liquefying, it flows down too quick (as a result of high ease) to sufficiently ingest warmth for any huge ascent in temperature. Then again, if the softening purpose of the slag is high, for example, of essential slag, it softens at a lower level in the furnace and achieves the tuyere level at a high temperature. Along these lines, essential slag i.e. high liquefying slag, warmth up the hearth while low dissolving slag cool the hearth. The cooling blast of low softening slag is because of lower temperature of dissolving as well as a result of the quicker drop to the hearth and more prominent interest of the hearth for decrease of iron and manganese oxides. In this manner, the smoothness and the liquefying qualities of the slag assume a real part in the control of hearth warmth. Henceforth exceedingly liquid and amazingly thick slag are extremes and ought to be avoidable practically speaking.

The flowlining of slag attributes can be attempted by comprehension the blast of distinctive variables like Al_2O_3, CaO/SiO_2, MgO on the liquidus temperature, flow temperature, viscosity, desulphurization and soluble base evacuation limit.

2.1.2 Composition of Blast Furnace slag

Table 2.1 Compositions of Blast Furnace Slag

Constituent	Weight Per cent
Lime (CaO)	32 to 45
Magnesia (MgO)	5 to 15
Silica (SiO_2)	32 to 52
Alumina (Al_2O_3)	7 to 16
Sulfur (S)	1 to 2
Iron Oxide (Fe_2O_3)	0.1 to 1.5
Manganese Oxide (MnO)	0.2 to 1.0

2.1.3 Formation of Slag at different zones

Primary or stack, Bosh & Hearth slag

The essential slag of generally low liquefying point which frames in the lower piece of the stack or in the gut comprises of FeO-containing silicate and aluminates with differing measures of lime which has gotten to be joined relying on the level of calcination experienced. As the slag plummets, ferrous oxide is quickly diminished via carbon and in addition by CO. As the lime is constantly ingested, the first $FeO\text{-}SiO_2\text{-}Al_2O_3$ framework quickly changes to the $CaO-SiO_2-Al_2O_3$system with some minor contaminations going with the burden[1.0]. The disintegration of lime and the way to deal with the $CaO-SiO_2-Al_2O_3$ framework is more declared. As the fluid essential slag keeps running down the bosh and loses its fluxing constituent FeO, the liquidus temperature likewise increments. On the off chance that in this manner, the slag needs to stay fluid it must move down to more smoking parts of the furnace as quickly as its softening point is raised. As the diminishment of FeO is very nearly finish over the tuyeres the subsequent bosh slag, made basically out of $CaO-SiO_2-Al_2O_3$[2.0].The hearth slag or last slag is framed on disintegration of the lime which was not fused in the bosh and on assimilation of the coke powder discharged amid combustion. The arrangement is pretty much finish in the combustion zone. Hearth slag chiefly made out of $SiO_2-Al_2O_3$-CaO-MgO.

2.1.4 Slag Liquids Temperature

In spite of the fact that the real slag contains a few components,theliquidus temperature of a slag can largly be characterized regarding four constituents to be specific SiO_2, Al_2O_3, CaO and MgO as these constituent record for more than 96 every penny of the slag composition.A extensive measure of writing has been distributed on the liquidus temperature of manufactured slag. Osborn has displayed the liquidus temperature as quaternary graph. There is no situated paradigm to choose a particular estimation of liquidus with the exception of that (a) the liquidus temperature ought to be such that enough superheat is accessible to keep up satisfactory smoothness of the slag (viscosity ought to associate with five balance however surely under 10 balance) and (b) the liquidus temperature ought to be too high nor too low. The liquidus temperature of common slag is lower than engineered slag, the diverse depents on the sort and amount of the contaminations present (MnO, TiO_2, feO, S, Na_2O, k_2O, and so on.) aswell as upon the arrangement of the essential slag. The minor constituent go about as fluxes and bring down the liquidus temperature beneath that esteem which would be gotten if the four noteworthy constituent were available in the slag. The real liquidus temperature of the slag ought to be in the scope of 1300-1400 ^oC. It is to be inferred that the bring down the liquidus temperature determined, the lower is the basicity of the slag which is preffered and if higher liquidus temperature can be endured, higher basicity operation can be endeavored.

2.2 Blast Furnace Operations

An blast furnaceis a kind of metallurgical furnace utilized for refining to deliver modern metals, by and large iron, additionally others, for example, lead or copper. In an blast furnace, fuel, metal, and flux (limestone) are persistently supplied through the highest point of the furnace, while a hot blast of air (at times with oxygen advancement) is blown into the lower segment of the furnace through a progression of funnels called tuyeres, so that the substance responses happen all through the furnace as the material moves descending. The finished items are typically liquid metal and slag stages tapped from the base, and vent gasses leaving from the highest point of the furnace. The descending flow of the mineral and flux in contact with an upflow of hot, carbon monoxide-rich ignition gasses is a countercurrent trade process.

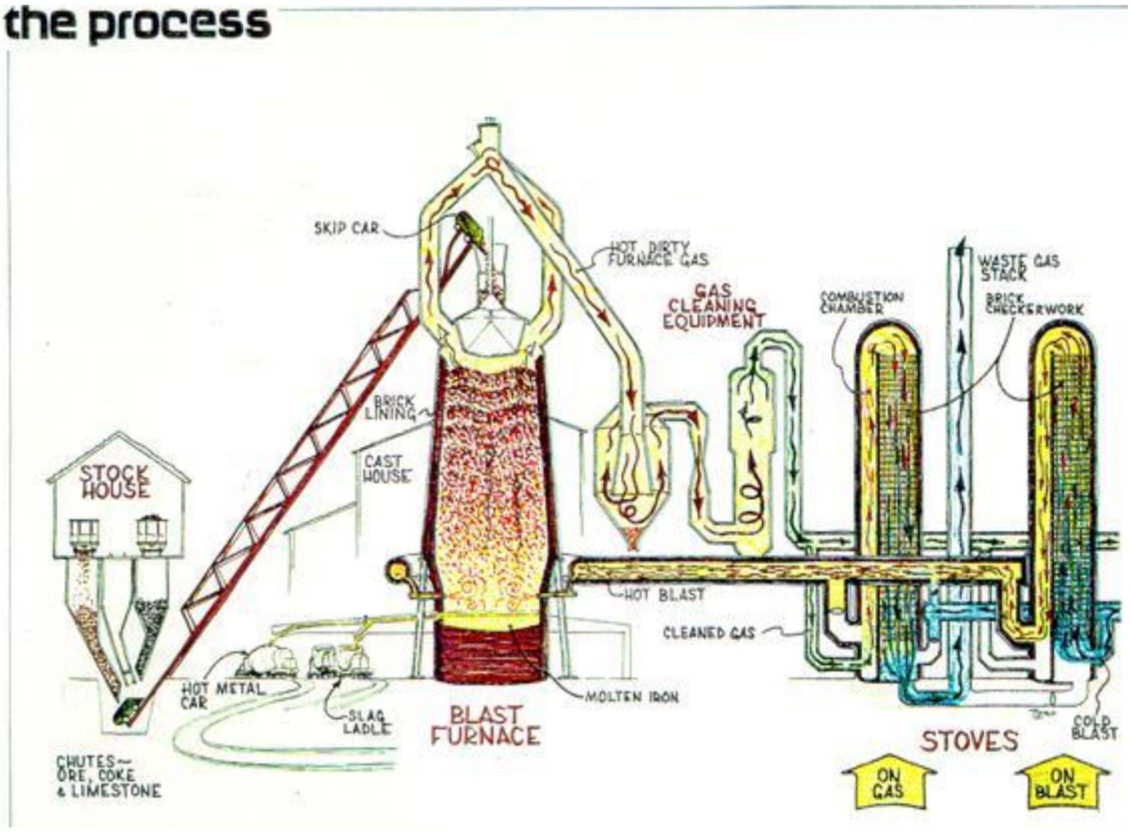


Fig. 2.2 Schematic diagram of Blast furnace

2.3 Reactions in the Blast Furnace

Blast furnaceis, from a physic-synthetic perspective, a monster counter-current heat exchanger and concoction reactor. The hot rising gasses up the plunging charge material, joined by a mixture of physical change and concoction reactions.The critical responses occuring inside of the can be depicted through the accompanying steps demonstrating how the diminishing specialists differs relying upon the stature in the furnace (i.e. on the Temperature).

At 500 °C $3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$ $Fe_2O_3 + CO \rightarrow 2FeO + CO_2$
At 850 °C $Fe_3O_4 + CO \rightarrow 3FeO + CO_2$
At 1000 °C $FeO + CO \rightarrow Fe + CO_2$
At 1300 °C $CO_2 + C \rightarrow 2CO$
At 1900 °C $C + O_2 \rightarrow CO_2$ $FeO + C \rightarrow Fe + CO$

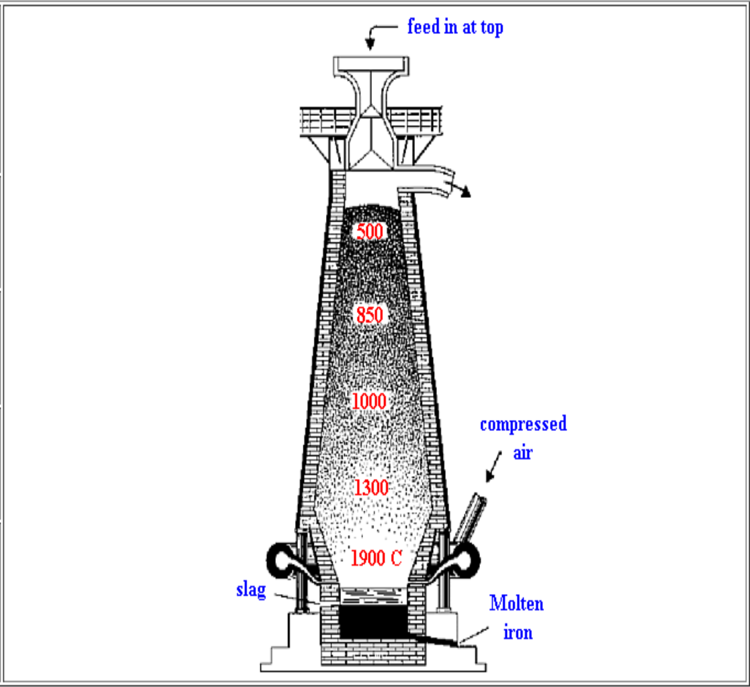


Fig. 2.3 Diagramatic representation of the distribution of temperature of the gas for the reduction of   iron ore in an ungraded burden charge.

2.3.1 Reactions in the Upper zone

In this zone, the burden is rapidly heated from the ambient temperature to about 800 ^{0}C withine a distance of 4-6 m from the stock level and the gas coming from the middile zone cools down from 900 ^{0}C to 100-200 ^{0}C as it leaves the furnace top. The main reactions that occure inthis zone are narrated below.

Reduction of iron oxides

$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2 + 10.330$ kcal

$Fe_3O_4 + CO = 3FeO + CO_2 – 8.75$ kcal

$FeO + CO = Fe + CO_2 + 3.99$ kcal

Water-Gas Shift Reaction

The temperature dependence of the equilibrium constant of the homogeneous water-gas reaction,

$CO + H_2O = CO_2 + H_2$ +9680 cal

Corbon deposition

Thermodynamically corbon deposition from CO by the reaction

$2CO = CO_2 + C$ + 41210 cal

Carbon deposition can occure on the surface or in the pores of ores, sinters or pellets or inside refractory brickworks wherever redused iron provides the active surface for catalysing the reaction.

2.3.2 Reaction in the middle zone

This zone extends from the upper zone (4-6m below the stock level) downwards to 3-5m above the tuyere level. It is a moderate temperature zone where the temperature range between 800-1000 ^{0}C. The height of this zone is considered and may occupy 50-60 percent of the shaft height (about 75% of the shaft volume) in modern furnace.

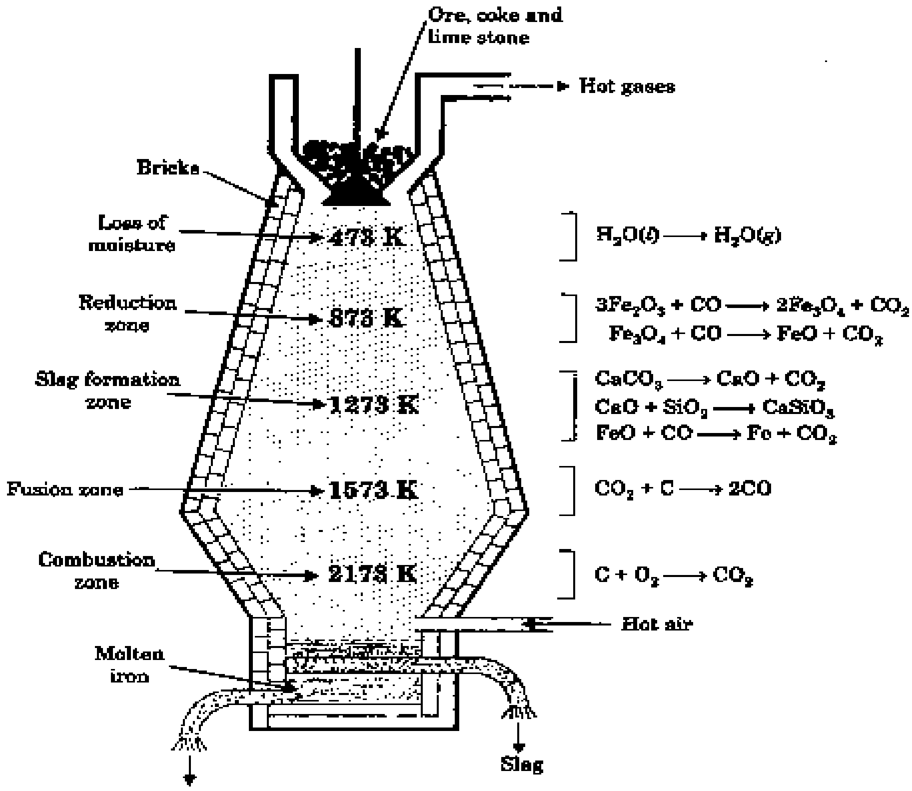


Fig. 2.4 Schematic representation of reactions of blast furnace

Indiect Reduction or stack reaction

- $3Fe_2O_3 + CO = 3FeO + CO_2$ at 400°C – 600°C
- $Fe_3O_4 + CO = 3FeO + CO_2$ at 600 °C - 800 °C (FeO unstable below 570 °C)
- $2CO = C + CO_2$ at 540 - 650 °C (boudouard or carbon deposition reaction)
- $FeO + CO = Fe + CO_2$ at 800 °C - 1100 °C
- $CaCO_3 = CaO + CO_2$ at 900 °C

Onset of slag formation at about 1100 °C;

Direct Reduction or hearth reaction at 1200 to 1800 ^{o}C

- $P_2O_5 + 5C = 2P$ (in Fe) + 5CO
- MnO + C = Mn (in Fe) + CO
- SiO_2 + 2C = Si (in Fe) + CO
- S (in Ore + Coke) + CaO + C = CaS (in Slag) + CO
- C (in Coke) = C (in Fe).
- FeO + C = Fe + CO

2.3.3 Reaction in the Lower zone

The temperature of the lower zone is over 900-1000^{o}C. The zone reaches out from 3-5 m over the tuyere level to the hearth base. The tuyere gas chills off from the fire temperature to 900^{o}C if limestone is available or to 1000^{o}C in the event that it is missing. It takes 0.7-3 hours enemy the weight to descentd from the gut to the tuyeres. A vriety of physical and synthetic procedures occure in this zone, namely,calcination of limestone, direct lessening of iron from unreduced wustite and silicates, direct decrease of silicon,manganese,phosphorus,sulphur, soluble base metals,lead,zinc,cromiumand to a little degree titanium,aluminiumetc. The combination of slag and metal, carburisation of iron, blazing of coke, oxidation of components before the tuyere and so on additionally occure in this zone.

$$CaCO_3 = CaO + CO_2 - 43350 \text{ cal}$$

2.4 Different zones of Blast Furnace

- Granular zone
- Cohesive zone
- Active coke zone
- Tuyere zone
- Stagnant coke zone
- Hearth zone

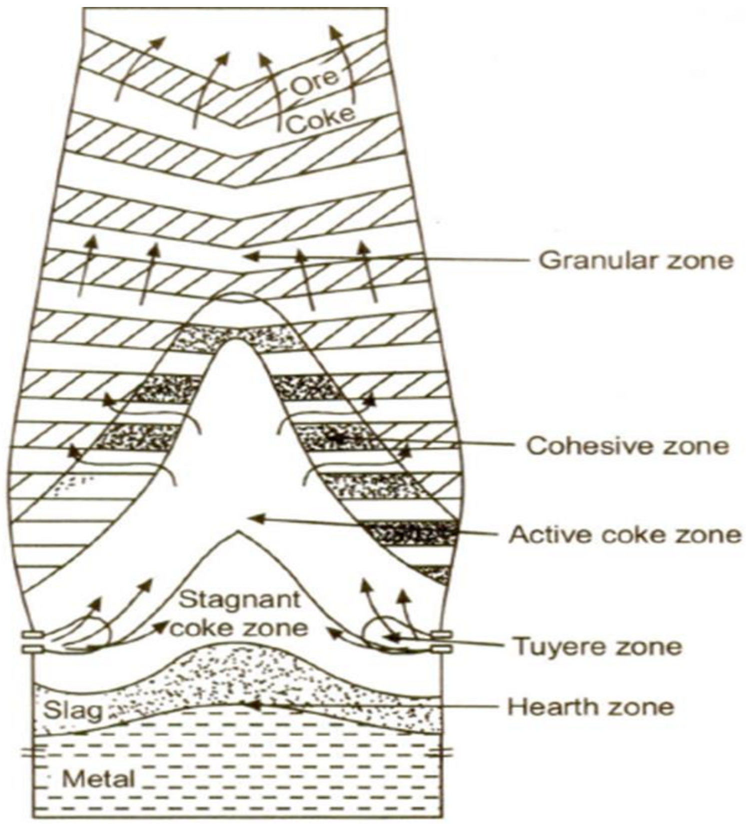


Fig. 2.5 Schematic representation of different zones of blast furnace

2.4.1 Cohesive Zone

Out of five zones the firm zone assumes the most critical part in the B.F. operations.This zone is likewise called softening dissolving zone. This is the zone where the ferrous weight mollify and melt.Its shape, position and degree in the B.F. influence the gas flow pattern.The weight loses its penetrability. Gas flow happens just through the coke layers.Loss of penetrability is created by fluid stage in the ferrous burden.The fluid development causes a weight drop.In the firm zone the strong get disfigured deu to the heaviness of the burden.This distorted may possess the hole between the strong ferrous pieces additionally bringing about loss of porousness.

The distinctive phenomena concurrent happening in the durable zone are;

a) Softening and dissolving of the oxide stage

b) Carburisation of the metalic stage

c) Softening and dissolving of the metalic stage.

Softening and dissolving of the oxide stage will be influenced by ;

a) The amount of non ferrous oxide (Slag previous) present

b) Distribution, Morphology, Chemistry of slag formers

c) Degree of prereduction (This will influence the accessibility of FeO as a slag previous)

Softening and liquefying of the metal stage will rely on upon :

a) carbon substance of metal stage

b) cross sectional zone of metal stage

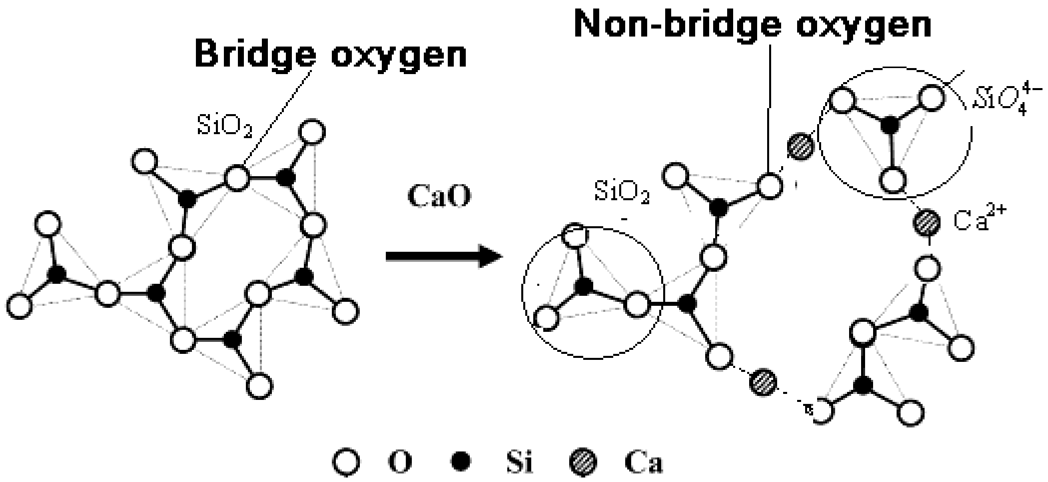
2.5 Slag Viscosity

The Viscosity of any slag has an essential blast on the furnace execution as it oversee the response energy by affecting dispersion rate, warmth exchange and headstrong wear in the furnace. The structure of the slag, which is controlled by slag piece, has a significant blast on its viscosity. Slag containing alumina-silicate are thick in light of huge three-dimensional system made out of Al-O and Si-O bonds win even in the liquidus state. That is the reason the viscosity of such slag is high. Expansion of fundamental oxide, for example, CaO and MgO decrease the viscosity by breaking the three-dimensional system into discrete silica-tetrahedral, which flow all the more effectively.

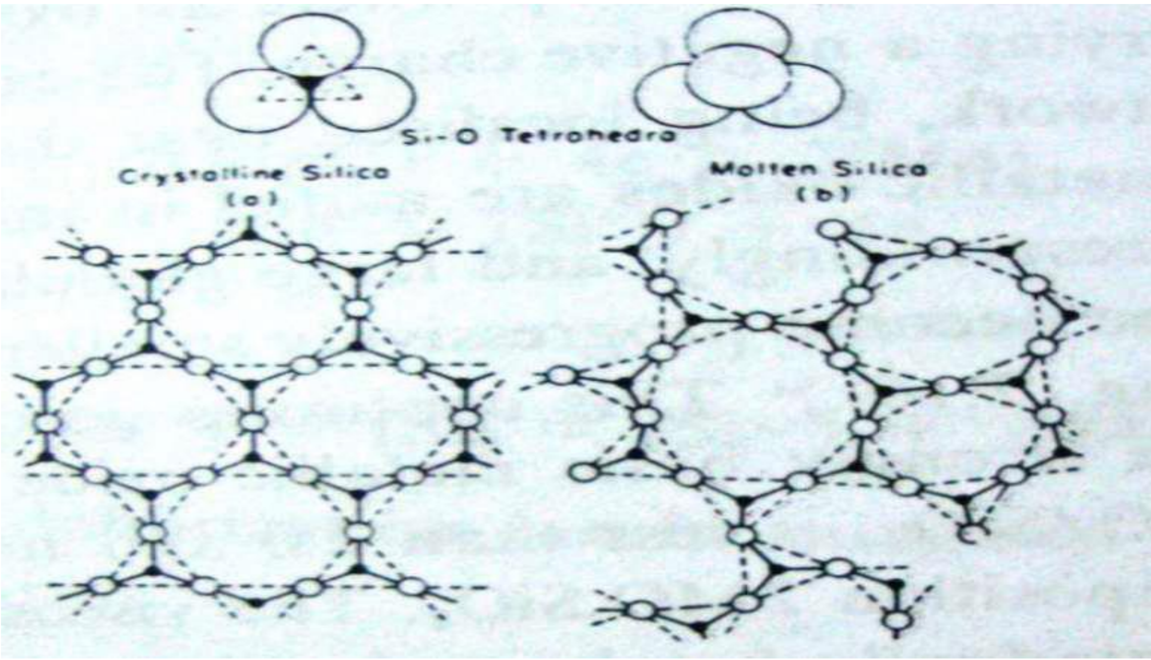
Distributed data demonstrates that the viscosity changes are little as the temperature increments over the liquidus temperature, yet even little variety can influence the progress of specific responses and all the more particularly, of the desulphurisation response. The way of the blast of diverse oxides is not clear, on the other hand, it creates the impression that if a slag is totally fluid, the expansion of a mole of fundamental oxide-CaO, MgO, MnO or Na_2O_3 delivers very nearly comparable blasts. As respects TiO_2 and FeO, the blast could be like the other fundamental oxides on a molar premise or free relying upon the way of the essential slag.

2.6 Slag Structure

Liquid slag are homogenous melts including oxides of silicon and distinctive parts. They are known not Metallurgy & Material Engineering properties and involve essential and complex particles. Examination of solid silica shows that silicon includes the point of convergence of a tetrahedron enveloped by 4 oxygen particles, one at each of the four corners. Each oxygen particle is joined to two silicon particles and the framework is consistent in three estimations. These tetrahedral can share just corners so that when every corner oxygen particle is shared, the substance confined will have a general stoichiometric comparison of SiO_2. A Si particle has 4 charges. As every oxygen atom of the tetrahedron has a waiting valence, in this way, the SiO_2 pack passes on 4 negative charges, i.e. $(SiO4)^{4-.}$ In the crystalline state the tetrahedral approach of the silicon and oxygen particles is symmetrical. The solid structure does not encounter any sudden change on blend, clearly. In fluid or vitreous silica the structure gets the chance to be twisted however a substantial segment of the corners stay shared. The viscosity of fluid silica is high (≈ 105 P), the corners being associated immovably in all headings in an interminable framework. The social affair, $(SiO_4)^{4-}$ which is seen as individual tetrahedron with silicon at within and oxygen at the four corners, can be relied upon to exist as molecule in the eccentric silicate. Estimation of the imperativeness of incitation for Metallurgy & Material Engineering conductance and distinctive results show that the development of CaO, MgO or other metal oxides to fluid silica achieves the breakdown of the three dimensional silicon-oxygen frameworks into silicate particles. The central purpose for the breakdown system is the interest amidst silicon and oxygen. This depends on upon their relative valances and ionic radii. Right when lime or Magnesia is added to fluid Silica, two silicon-oxygen bonds are opened up offering rising to an open shared corner where oxygen is incorporated, each oxygen passing on a negative charge. The cations pass on in the interstices of the framework, being limited near to the charged oxygen. As the metallic oxides are incorporated extending entireties, the Si-O



securities break correspondingly, and generous globular or ring sort silicate particles are formed. These get the opportunity to be alterably more diminutive as the metal oxide substance increases as their no keeps growing. As the strong silicate frameworks break, the viscosity of the melt lessens profoundly as viscosity of a material relies on upon its creation and in addition on its structure. The easier going the structure is the less is the viscosity. [2]



2.7 Effect of MgO and Al_2O_3 of Final Slag

Shih-Hsien Liu, Jia-Shyan Shiau, Chung-Ken Ho, By and large, diminishing slag volume of blast furnaceoperation can prompt the lower fuel proportion and higher profitability. This strategy may bring about lower MgO content in the last slag that may influence its ease. Henceforth, the target of this study was to comprehend the blast of MgO and Al_2O_3 on the smoothness of last slag. The test results demonstrated that the lower liquids temperature and the better viscosity soundness lay in the territory of MgO = 5-10%, Al_2O_3 = 30%, and C/S = 0.9-1.35 for the scope of organization considered. MgO substance in the scope of MgO = 5-10%, Al_2O_3 = 20%, C/S = 0.9-1.35. Also, slag smoothness turned out to be more awful with high Al_2O_3 content under the states of MgO = 5-10%, C/S =0.9-1.35. This study recommended the MgO substance could be brought down from current 6 to 12% in the states of Al_2O_3 =20%, C/S = 1.35 under the steady blast furnaceoperation with high warm level. Moreover, this formula of lower MgO content (6%) had been executed in CSC's BF operation to diminish the slag volume. Test results show that the lower liquids temperature and the better viscosity steadiness of slag lay in the states of MgO = 6%, Al_2O_3 =20%, and C/S =1.35 for the variety of MgO substance (5-10%).

2.8 Effect of liquidus Temperature in high basicity and high Al_2O_3 system

Yanli Wang b, Du Sichen, Jimmy Grana. The liquidus temperature in the high basicity district in the Al_2O_3 (30 mass%)-CaO-MgO-SiO_2 framework were dead set tentatively at 1500 and 1600 ^oC utilizing the extinguish strategy took after by warming magnifying instrument investigation. Taking into account the trial information, a stage graph of the Al_2O_3 (30 mass%)-CaO-MgO-SiO_2 (< 20 mass%) area was built for 1500 and 1600^oC. Also, the exercises of MgO, CaO and Al_2O_3 at 1500oC were evaluated utilizing the stage outline information. Based on the exploratory results, a stage graph of the Al_2O_3 (30 mass%)–CaO–MgO–SiO2 segment was built for 1500 and 1600^0C for SiO_2 substance beneath 20 mass%. In correlation with the work by Osborn et al. [2], the fluid religion ought to be to some degree stretched out as indicated by the present work. Then again, the outcomes from the present work for the most part concur well with the stage chart proposed by Osborn et al. [2]. The exercises of CaO, MgO and Al_2O_3 were additionally evaluated inside of the same.

2.9 Effects of Basicity and FeO Content on the Softening and FlowTemperatures of the CaO-SiO_2-MgO-Al_2O_3 Slag System

Weng-Sing Hwang Hsin-Chien Chuang Shih-Hsien Liu.The effects of basicity (CaO/SiO_2) and FeO content on softening and melting temperatures of synthetic high alumina slag were investigated. Basicity values between 1.83 and 0.55, and the other varied the FeO contents between 10% and 50% at constant basicity. The lowest softening and melting temperatures of the CaO-SiO_2-5%MgO 10% Al_2O_3 samples occurred at a basicity of 0.55 while for the CaO-SiO_2-10%MgO-5% Al_2O_3 samples it occurred at 0.70. This corresponds to the liquidus temperatures on the CaO-SiO_2-MgO- Al_2O_3 quaternary phase diagram. At constant basicity, the deformation temperature of CaO-SiO_2-10%MgO-5% Al_2O_3 samples was found to be higher than that of CaO-SiO_2-5%MgO-10% Al_2O_3 samples. Lastly, the addition of FeO below 20% to the CaO-SiO_2-MgO- Al_2O_3 system significantly decreased the softening and melting temperatures of the slag samples.

2.10 Flow Temperature of the chose range in CaO-MgO- Al_2O_3-SiO_2 Slag System.

XU Ji-tooth, ZHANG Jie-yu , JIE Chang' , TANG Lei , CHOU Kuo-chih, Basicity and the Al_2O_3 substance had evident blast on the trademark temperatures of the chose slag. The densities of the chose quaternary CaO-MgO-Al_2O_3-SiO_2 slag with low silica were measured by the Archimedean technique in a wide temperature range from 1773 to 1873 K. The blasts of temperature, SiO_2 content and optical basicity were examined. It is demonstrated that viscosity diminishes give or take directly with an increment in temperature. Under the same CaO content, the viscosity diminishes with expanding of SiO_2 substance and increments with optical basicity expanding. The outcomes likewise demonstrated that the optical basicity has extraordinary blast on viscosity. The viscosity increments as a direct association with optical basicity expanding for every level of CaO substance.

2.11 Sulfide Capacity of High Alumina Slag

AMITABH SHANKAR, MARTEN GORNERUP, A.K. LAHIRI, and S. SEETHARAMAN, Sulfide limit increments with the increment in basicity. The MgO builds the sulfide limit of slag past the 5 % level. The connection between sulfide limit and the redressed optical basicity set forward by Mills considering the accuse remuneration was investigated. Combined of the connection between sulfide limit and temperatures, a novel and exact computation model of sulfide limit was proposed , which was connected to ascertain the sulfide limits of $CaO-Al_2O_3-SiO_2-MgO$ and $CaO-Al_2O_3-SiO_2-MgO-TiO$ frameworks, where the aggregate of the CaO and MgO fixations in the slag must be noted lower than the Al_2O_3 concentration.

2.12 Strategies for the production of low silicon and low sulphur hot metal at Rourkela Steel plant

A.L.Kundu,S.C.Prasad, H.S.Prakash and M.Prasad, To maximize the removal of alkalis from the furnace, it is necessary to keep the basicity of the slag as low as possible.

2.13 Evaluating Slag Viscosities in the $CaO-Al_2O_3-MgO-SiO_2-(TiO_2)$ System

Andre Costa e Silva, slag is discriminating parts in a few iron and steelmaking procedures. In iron making, distinctive slag with different properties are utilized as a part of the diverse preparing strides from softening and melting to constant throwing. Thermodynamic properties, viscosity and surface strain are among the most essential properties considered in the outline of slag pieces for steel preparing. Slag viscosities demonstrates that viscosity relationships with compound organization, basicity (both synthetic and optical), and all the more as of late with slag constitution have been endeavoured with diverse degrees of achievement. The nature of the conformity is examined and its present constraints. Future strides in the model advancement include its expansion to combine FeO, CaF_2 and TiO_2.

2.14 Evaluation of Viscosity of Molten SiO_2–CaO–MgO–Al_2O_3 Slag

Masashi NAKAMOTO, Toshihiro TANAKA, Joonho LEE and Tateo USUI, The viscosity of the liquid SiO_2–CaO–MgO– Al_2O_3 slag was measured utilizing a turning barrel technique at high Al_2O_3 focus locales to scan for a slag with low flow temperature and low viscosity. The trial aftermaths demonstrated that the viscosity of liquid 35mass% Al_2O_3–43.1mass%CaO– 7.5mass%MgO–14.4 mass%SiO_2 slag at 1673 K was lower than 0.6 Pa.S that fulfils the ease in blast furnaceoperation. The trial results were contrasted and the ascertained aftereffects of the viscosity model inferred by the creators. The viscosity of liquid SiO_2–CaO–MgO–Al_2O_3 framework can be assessed from our model in wide Al_2O_3 concentration range.

2.15 Effect of MgO and Al_2O_3 Contents on Viscosity ofSlag Containing FeO

Joo Ro KIM, Young Seok LEE, Dong Joon MIN, Sung Mo JUNG1 and Sang Ho YI, The viscosities of CaO–SiO_2–Al_2O_3–MgO–FeO slag were measured under states of C/S_1.1–1.4,10–18 mass% Al_2O_3, 3.5–10 mass% MgO and 5 mass% FeO. The bosh slag with 10 mass% Al_2O_3 substance had the most reduced dissolving temperature and the greatest strong fluid existing together district at around 5 mass% MgO, while in the event of 14 mass% Al_2O_3, an increment in a MgO content from around 3.5 to 10 mass% raised the liquefying purpose of bosh slag. The viscosity of bosh slag likewise displayed a base quality at around 7 mass% MgO at temperatures over 1723 K. On the other hand, with expanding Al_2O_3 content, the viscosity of bosh slag expanded at an altered C/S and MgO content. In view of the liquefying temperature and the conduct of viscosity at an altered temperature, it could be suggested that the MgO and Al_2O_3 substance in bosh slag ought to be kept up around 5 and 10mass%.

2.16 Effect of slag Viscosity of CaO-SiO_2-MgO-Al_2O_3Slag with low Basicity and high Alumina

TANG Xu-long', ZHANG Zuo-tai' , GUO Min' , ZHANG Mei' , WANG Xi-dong', slag has mostly made out of the quaternary slag creations of CaO-SiO_2-MgO- Al_2O_3 with basicity (mass proportion of CaO to SiO_2) going from 0.5 to 0.9 and alumina extending from 5% to 20% were researched through a pivoting chamber technique. The test results showed that the viscosities diminishes with expanding basicity over the hemispherical temperature, and expanded with expanding alumina content, and the most extreme qualities were come to and as the alumina substance was 20%, trailed by the decline with further expanding alumina content because of its amphoteric conduct. The amphoteric conduct of Al_2O_3 additionally performed in the relationship in the middle of viscosity and non-connecting oxygen every tetrahedral-composed iota (NBO/T), and the viscosities diminished with expanding the NBO/T aside from the slag with basicity 0.5 and Al_2O_3 20% which have a low NBO/T worth and a low viscosity than others.

2.17 Viscous behaviour of CaO-SiO_2- Al_2O_3-MgO-FeO slag

Y.S. LEE, J.R. KIM, S.H. YI, and D.J. MIN, The Viscosity of CaO-SiO_2-Al_2O_3-MgO-FeO slag were measured under states of CaO/SiO_2=1.15–1.6, 10–13 per cent Al2O3, 5–10 per cent MgO and 5–20 per cent FeO. Slag viscosity diminished with expanding FeO content at an altered basicity (CaO/SiO_2) of slag. Slag viscosity at low FeO (<7.5 per cent FeO) displayed a base esteem by expanding MgO content in slag. viscosity diminished with expanding slag basicity up to 1.3 while it expanded as slag basicity expanded from 1.3 to 1.5. Subsequently, it was suggested that the main thrust for the declines of slag viscosity would be an increment in depolymerisation of silicate system at C/S≤ 1.3, while the Viscous behaviourat C/S>1.3 would be expanded with expanding the compound capability of essential strong stage e.g. dicalcium silicate. In this manner, it was affirmed that slag viscosity in fundamental slag framework (C/S>1.3) could be controlled by the substance capability of dicalcium-silicate.

2.18 Effects of Basicity and MgO content on the viscosity of the SiO_2−CaO−MgO−9wt%Al_2O_3 slag

Yun-ming Gao, Shao-bo Wang, Chuan Hong, Xiu-juan Ma, and Fu Yang The blasts of basicity and MgO content on the viscosity of SiO_2−CaO−MgO−9wt% Al_2O_3 slag with basicity from 0.4 to 1.0 and MgO content from 13wt% to 19wt% were examined utilizing the pivoting barrel or rotating viscometer system. A relationship between the viscosity and the slag structure was controlled by Fourier change infrared (FTIR) spectroscopy. It is shown that the unpredictable system structure of the slag melt is depolymerized into easier system units with expanding basicity or MgO substance, bringing about a constant diminishing in viscosity of the slag. Under the present exploratory conditions, expanding the basicity is discovered to be more viable than expanding the MgO content in diminishing the viscosity of the slag. At higher temperatures, the increment of basicity or MgO substance does not considerably diminish the viscosity of the slag, as it does at lower temperatures. The computed enactment vitality of viscous flow is somewhere around 154 and 200 kJ/mol, which diminishes with an increment in basicity from 0.4 to 1.0 at a settled MgO content in the scope of 13wt%.

2.19 Measuring and Modelling of viscosity of selected CaO-MgO-Al_2O_2-SiO_2 slag

Jifang Xu1, a, Jieyu Zhang1, b, Chang Jie1, c, Gongyuan Liu1, d, and Fei Ruan

Viscosity of chose quaternary CaO-MgO-Al_2O_3-SiO_2 slag have been measured by rotational chamber technique up to a temperature of 1875K. The blast of expanding temperature was researched and it was demonstrated that viscosity diminished, not surprisingly, with expanding temperature. The viscosity increments with expanding the proportions of CaO/Al_2O_3, and taking after by diminishing with the further were expanding the proportions of CaO/Al_2O_3. A utilization of Iida's viscosity model has been made. The Iida model gave great viscosity with the deliberate viscosity values.

2.20 Viscosity of slag with optical basicity

Xiao-jun Hu1, Zhong-shan Ren,Guo-hua Zhang1, Li-jun Wang1, and Kuo-chih Chou,

In the present study a viscosity model was proposed for blast furnace slag. In the model the actuation vitality was ascertained by the optical basicity remedied for cations needed for the charge pay of AlO_4^{5-}. By utilizing the remedied optical basicity to fuse the blast of the charge parity blast of Al^{3+} particles on the viscosity, another model is proposed to gauge the viscosity of blast furnace slag frameworks CaO-Al_2O_3-SiO_2, CaO-Al_2O_3- SiO_2-MgO, and CaO-Al_2O_3-SiO_2-MgO-TiO_2, and the mean deviations of under 25% is accomplished. The viscosity diminishes with the increment of MO substance, and the increment of the amended optical basicity additionally makes the viscosity decay. TiO_2 is available in alumina-silicate softens, the level of polymerization will decrease, There by the viscosity diminishes.

2.21 Viscosities of Iron Slag

Mao CHEN, Dianwei ZHANG, Mingyin KOU1, and Baojun ZHAO1, The viscosities of the modern and engineered iron blast furnace slag have been measured utilizing a hand crafted turning weave device. The tests were done utilizing Mo shaft and cauldron under ultra-high immaculateness Air flow. The microstructures and stage syntheses of the extinguished slag tests were controlled by Electron Probe X-beam Microanalysis (EPMA) after the viscosity estimations. It was observed that the viscosities of the modern slag are lower than those of the comparing engineered slag produced using immaculate Al_2O_3, CaO, MgO and SiO_2. The distinction in viscosities between Metallurgy & Material Engineering slag and engineered slag will give helpful evidences when applying the aftereffects of the manufactured slag to the genuine iron blast furnaceslag. The initiation vitality of both modern and engineered slag is 174 kJ/mol and increments with diminishing MgO fixation. Substitution of (CaO+SiO_2) or CaO by MgO can diminish the slag viscosity.

2.22 Relationship between structure and viscosity ofCaO–SiO_2–Al_2O_3–MgO–TiO2 slag

Shengfu Zhang, Xi Zhang, Wei Liu, Xuewei Lv , Chenguang Bai , Long Wang

Structure of the CaO–SiO_2–Al_2O_3–MgO–TiO_2 slag was concentrated on by atomic motion recreation at 1773 K. Furthermore. Part of TiO_2 as fundamental oxide was confirmed and it can be gathered that the structure of TiO_2 is generally like MgO contrasted with CaO. Parts of viscosities were measured for quantitatively making the relationship between the structure and viscosity with shifting basicity and TiO_2 increases. In addition, parameter αM was proposed to gauge charge-adjusting ability of M for [AlO_4] (where M signifies Ca^{2+}, Mg^{2+} ,Ti^{4+}) alongside the normal estimations of αCa, αMg and αTi equalling to 1.731, 1.282 and 1.092, individually, proposing that Ca^{2+} is specially adjusted for [AlO_4] thanMg2+ and Ti4+. In this manner, TiO_2 and MgO have an unmistakable blast on depolymerizing the structure of the slag than CaO in slag containing high Al_2O_3. At long last, the common logarithm of the deliberate viscosities displays a straight reliance on the part of Q^4 for Si, showing that the level of polymerization for Si is still the key variable which influences the viscosity notwithstanding the confused composition.

Chapter 3

EXPERIMENTAL DETAILS

3.1 Experimental Details: Theory and Procedure

3.1.1 Flow Characteristics of high alumina Blast Furnace Slag

High temperature microscope is used to determine flow characteristics of synthetic high alumina blast furnace slag sample. It has find out four characteristics temperatures which has to be studied:

a) Initial deformation temperature (IDT)
b) Softening temperature (ST)
c) Hemispherical or liquids temperature (HT)
d) Flow or melting temperature (FT)

The characteristic temperatures i.e. ST, HT and FT, are determined for different slag samples are used in the current study. Softening temperature (ST) is the temperature at which the outline of the shape of the specimen shrinks by one division or the temperature at which the distortion of the sample starts. Hemispherical temperature (HT) is the temperature at which the specimen has fused down to hemispherical shape and is measured as the temperature at which the height of the specimen is equal to half of its base length. Flow temperature (FT) is the temperature at which the specimen liquefies and is reported as the temperature at which the height of the specimen is equal to one third of the height that it had at the hemispherical temperature. In the present work, using multi- linear regression analysis, empirical equations have been developed to predict the ST, HT, and FT in terms of CaO/SiO_2 ratio, MgO and Al_2O_3 content. The calculated values of the characteristic temperatures using the empirical equations are compared with experimentally determined values for several blast furnace slag to verify the validity of the equations developed.

The followings characteristics are demarcated by heating microscope as per German Industrial Standards 51730 practice.

Initial Deformation Temperature (IDT)

Introductory deformity temperature or initial deformation temperature is that temperature at which the first gathering together of the edges of the block formed sample happens. Indeed this is the temperature at which the to begin with indication of the adjustment fit as a fiddle shows up. Rheological this temperature symbolizes the surface stickiness of the slag.

Softening Temperature (ST)

It is the temperature at which the layout of the state of the sample begins changing and is accounted for as the temperature at which the specimen contracts by one division or the temperature at which the mutilation of the sample begins. Rheological this temperature symbolizes to begin of plastic contortion.

Hemispherical or Liquids Temperature (HT)

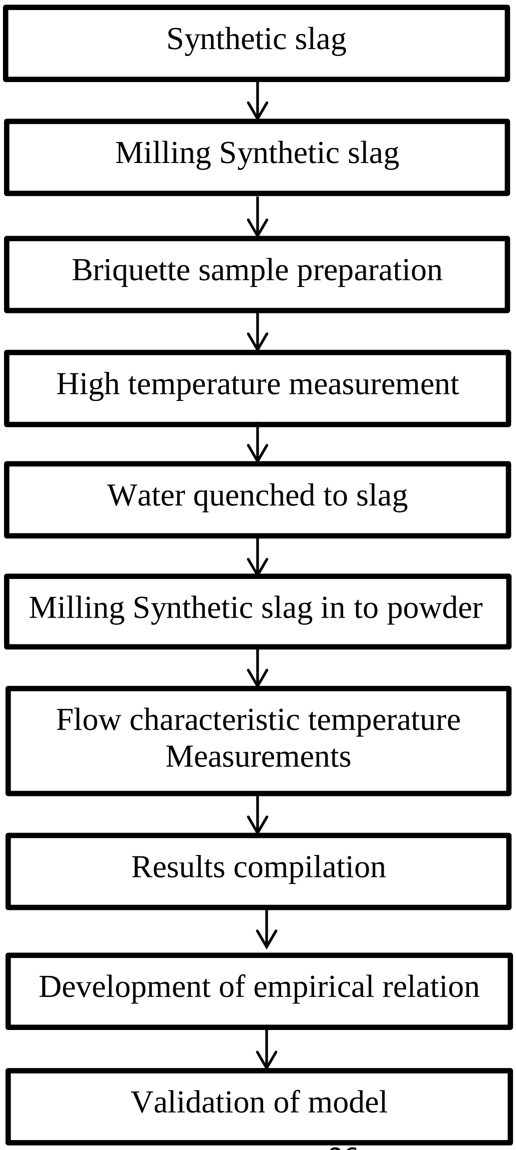
It is the temperature at which the specimen has intertwined down to hemispherical shape and is measured as the temp at which the tallness of the sample is equivalent to a large portion of its base length. This is characterized as the combination point or the dissolving point in **Germen Industrial Standards 51730**. Rheological this temperature symbolizes the drowsy stream of the slag.

Flow or Melting Temperature (FT)

It is the temperature at which the sample liquidities and is accounted for as the temperature at which the sample of the sample is equivalent to 33% of the tallness that it had at HT (hemispherical temperature). Despite of fact that a few books are reported at the temperature at which the sample turns into 33% of the beginning tallness. The previous is more exact and is generally acknowledged. Rheological this temperature symbolizes the fluid versatility of the slag.

3.2 Experimental procedure:

To measure the flow characteristics of high alumina synthetic blast furnace slag are followed in sequenced:



3.3 Heating microscope:

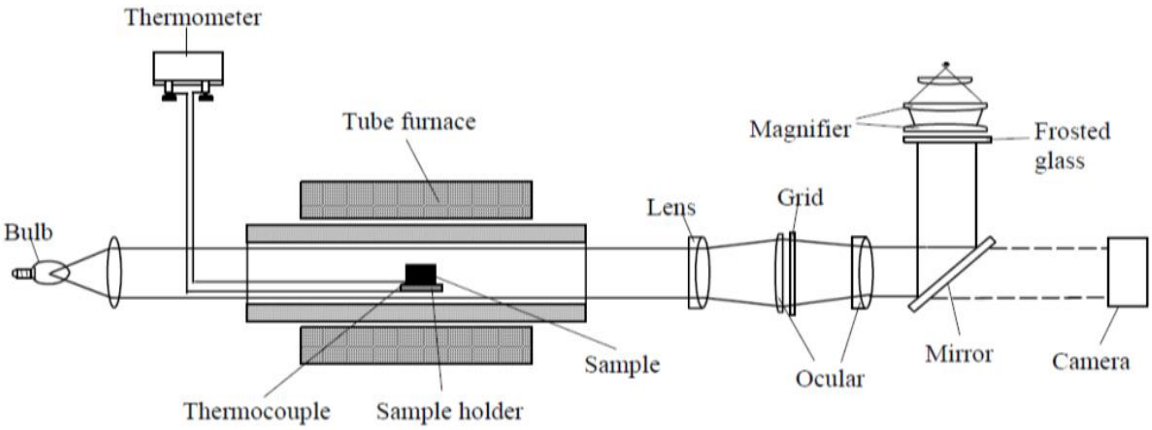
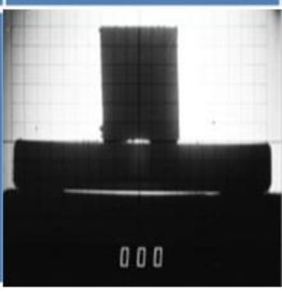
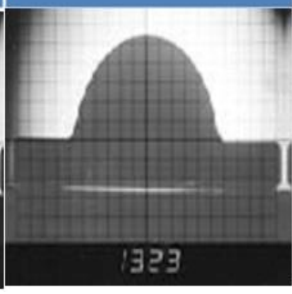


Fig. 3.1 Pictorial view of Leitz heating microscope.

<u>Fusion behaviour analysing of heating microscope:</u>

Test No	Original shape of sample	ST (°C)	HT (°C)	FT (°C)
1				

Different process involved:

Weighing:

After the oxides are furnace heated, they are then weighed and mixed according to their percentage composition in the digital weighing machine accurately.

Mixing:

After taking proper accurate weights of the oxides they need to be thoroughly mixed. The mixing of the major oxides is done in the abrasion tester machine mixer.

Pelletization:

Now the spherical shape pellets are made from the oxides sample by the help of distilled water and then kept in the dish plate.

Drying:

The dish plates carrying the spherical pellets are put in the oven for 3-4 hours for drying upto 120°C.

Furnace Heating:

The dried spherical pellets are put in the crucible and crucible is placed in the furnace for heating up to 1600°C which will take a whole day.

3.4 Test Apparatus

3.4.1 High Temperature Heating Microscope

The Heating Microscope technique is embraced for recording the characteristics temperatures. A photo of the Leitz warming magnifying lens is indicated in Fig. The specimen, as a 3 mm 3D square, is warmed in an Electric furnace in the magnifying lens gathering. The shape change of the specimen as an aftereffect of warming is shot by a cam. A matrix division which is at the same time captured with the sample and the temperature to which the specimen is being warmed encourage recognizable proof of the four characteristics temperatures.

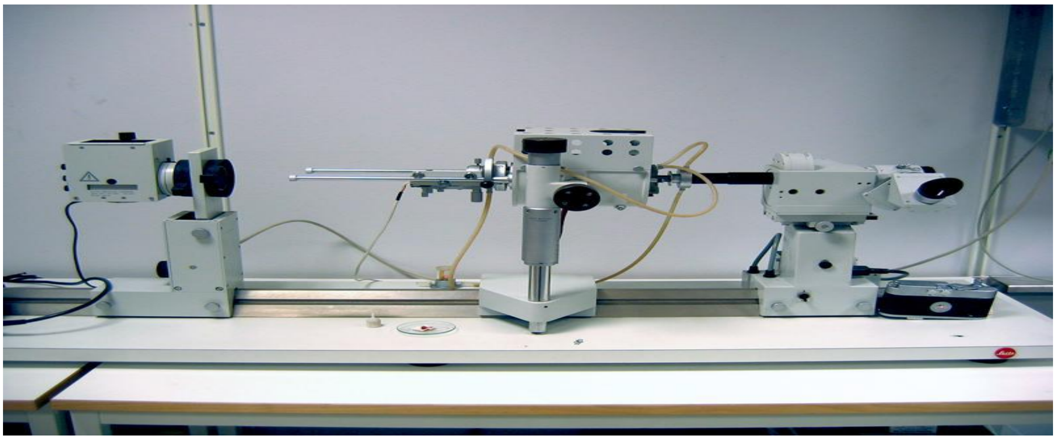


Fig. 3.2 Leitz heating microscope.

3.4.2 Planetary Ball Mill

These factories are additionally eluded as divergent plants and are utilized to pound tests into colloidal fineness by creating high crushing vitality. Fig. speaks to a four positioned planetary factory introduced by Gilson Company. The samples are put in one of the awful and various balls are included as demonstrated. The wretched is secured by the spread plate and afterward it is mounted in the machine. Once the vilest are mounted and secured, the machine is useful. The dishes are free of the rotatable stage and the course of revolution of the dishes is inverse to the bearing of the rotatable stage. The movement takes after the teacup and saucer as seen in a percentage of the event congregations. Fig. - a four station Planetary Ball Mill Because of interchange expansion and subtraction of the divergent powers, the crushing balls rolls most of the way in the detestable and after that tossed over the vilest and afterward affecting the inverse dividers at high speeds.20g quickening is come to because of the planetary activity and the time for the granulating diminishes around 2/3 times than a straightforward divergent plant.

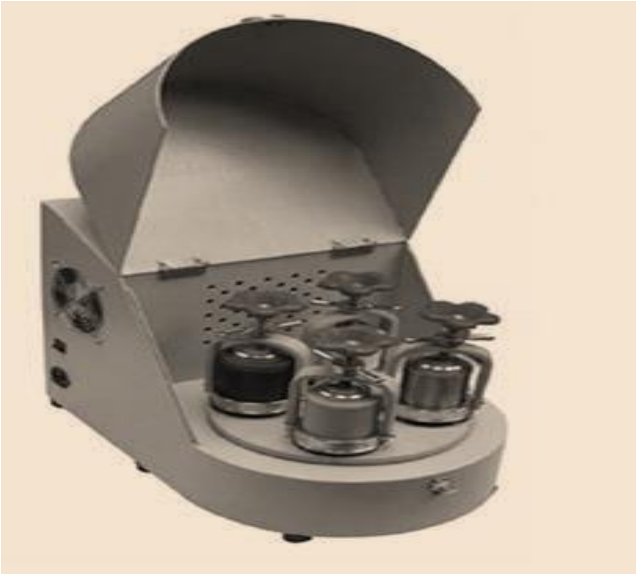


Fig. 3.3 Planetary Ball Mill

3.4.3 Abrasion Testing Machine

The Abrasion Testing blender machine is utilized to blend the slag tests. An altered 10 grams of aggregate weight (Containing weighted rate arrangement of all the significant oxides) of the mix of real oxides are taken into a plastic holder. There are 3 such holders that can be assembling, making it 30 grams. Since the blending ought to be homogeneous and splendidly blended, each holder of 10 g is independently taken weights according to estimations. This plastic holder is then set in one of the 3 pivoting councils of the blender. An aggregate of 99999 transformations are needed for proper blending which is finished in 7 hours. 3 such sessions are needed for complete blending of 30 grams. So the aggregate 160 gram of the obliged manufactured slag test is arranged in 8 days. The blending is exceptionally homogeneous when done by this procedure and issues us completely blended oxides.

Fig. 3.4 Abrasion tester machin

3.4.4 Heating Furnace (maximum temperature at 1750 ^{o}C)

In this furnace the readied sample is warmed at a temperature of 1600oC to soften the specimen and water extinguished to discover shiny precious stone structure. Heating furnace takes 4 hour to finish the liquefying of the engineered high alumina slag test. At the point when the temperature came to at 1600oC than 1 hour to keep it hold the slag test.

Fig. 3.5 Rising hearth high temperature Furnace

3.5 X-Ray diffraction (XRD)

X-Ray beam diffraction method was utilized to distinguish the distinctive stages (basic stage/intermetallic stage/crystalline stage/non-crystalline stage) introduce in the covering. XRD examination was finished by utilizing X-perky MPD framework (PAN Analytical). Here Ni- separated Cu- Kα radiation utilized as a part of X- Ray diffract meter. d- Values got from XRD examples were contrasted and the attributes d-separating of every conceivable worth from JCPDS cards to get the different X-beam crests. Obtained d-spacing based on the equation.

$$n =2d\sin$$

Where, ʎ = Wavelength of characteristic x-rays

d= Lattice Interplanar Spacing of the crystal

& ɵ = x-ray incident angle

Fig. 3.6 X-ray Diffraction Machine

3.6 Viscosity of High alumina slag

Viscosities of slag organize an important physical property needed for an accepting of the mass transfer sensations in metallurgical methods. Viscosity is also the crucial that leads to a well understanding of the arrangement of slag. It is well-known that the viscosities of silicate slag decrease with the accumulation of basic oxides due to the violation of the silicate network. The measurements of slag viscosities often pose investigational challenges, especially to the superior of materials. The viscosity of high alumina blast furnace slag is measured by using Iida's viscosity model is based on the Arrhenius-type equation, where network arrangement of the slag is taken into explanation by using the so-called modified basicity catalogue Bi (j).

$$\mu = A\mu 0 \text{ EXP } (E/Bi^{(j)}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$A= 1.029 - 2.078 \times 10^{-3}T + 1.050 \times 10^{-6} T^{2} \ldots\ldots(2)$$

$$E = 28.46 - 2.0884 \times 10^{-2}T+ 4.000 \times 10^{-6} T^{2} \ldots\ldots(3)$$

$$\mu_0=\Sigma\mu_{0i} X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$Bi^{(j)} = (\alpha_{CaO} W_{cao} + \alpha_{mgo} W_{mgo})/(\alpha_{sio2} W_{sio2} + \alpha^*_{Al2o3} W_{Al2O3})$

$Bi^{(J)}$ = Modified basicity index

$\alpha^*_{Al2O3} = aB_i + bW_{Al2O3} + c$……………………..3

a, b, and c values of above equations for $CaO+MgO+Al_2O_3+SiO_2$ system are defined as given below

$a = 1.20*10^{-5} T^2 - 4.3552*10^{-2}T + 41.16$…………....4
$b = 1.40*10^{-7}T^2 - 3.4944*T + 0.2026$……………...5
$c = -8.00*10^{-6}T^2 + 2.5568*10^{-2}T - 22.16$…………..6

basicity ratio (B_i)is defined by the following equation

$B_i = (\alpha_{CaO} W_{CaO} + \alpha_{MgO} W_{MgO})/(\alpha_{Sio2} W_{Sio2} + \alpha_{Al2o3} W_{Al2O3})$

Table 3.1 Values for melting temperature (Tm) i, density (ρm) i, molar weight Mi., viscosity of hypothetical melts μ0i and specific coefficients αi.

	T_m (K)	ρ_m (10^3kg/m^3)	$M_{i.}$ (10^{-3}kg/mol)	μ_{0i} (mpa s)	α_i
SiO2	2001	2.20	60.08	0.13170exp (5613.5/T)	1.48
Al2O3	2313	3.04	101.96	0.14792exp (6679.5/T)	0.10
CaO	2873	2.39	56.08	0.13651exp (8664.4/T)	1.53
MgO	3073	2.49	40.30	0.14743exp (9393.1/T)	1.51

Table 3.2 Compositions of slag (In weight %)

Constituent	slag 1	slag 2	slag 3	slag 4	slag 5	slag 6	slag 7	slag 8
SiO2	30.47	29.52	28.57	27.62	29.09	28.18	27.27	26.36
Al_2O_3	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
CaO	33.52	32.47	31.43	30.38	34.9	33.81	32.72	31.63
MgO	6	8	10	12	6	8	10	12

Table 3.3 Composition of slag (In weight %)

Constituents	slag 9	slag 10	slag 11	slag 12	slag 13	slag 14	slag 15	slag 16
SiO2	27.82	26.95	26.08	25.21	26.66	25.83	25.00	24.16
Al_2O_3	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
CaO	36.17	35.04	33.91	32.78	37.34	36.16	35.00	33.84
MgO	6	8	10	12	6	8	10	12

Chapter 4

Results & Discussion

4.1 Flow characteristics of high alumina blast furnace slag

4.1.1 Different composiyions of blast furnace slag

Table 4.1 Chemical compositions of blast furnace slag

SI. No.	Al_2O_3	SiO_2	CaO	MgO (M)	CaO/SiO_2 (R)
1	30	30.47	33.52	6	1.1
2	30	29.52	32.47	8	1.1
3	30	28.57	31.42	10	1.1
4	30	27.62	30.38	12	1.1
5	30	29.09	34.90	6	1.2
6	30	28.18	33.81	8	1.2
7	30	27.27	32.72	10	1.2
8	30	26.36	31.63	12	1.2
9	30	27.82	36.17	6	1.3
10	30	26.95	35.04	8	1.3
11	30	26.08	33.91	10	1.3
12	30	25.21	32.78	12	1.3
13	30	26.66	37.34	6	1.4
14	30	25.83	36.16	8	1.4
15	30	25.00	35.00	10	1.4
16	30	24.16	33.84	12	1.4

The characteristic temperatures of the selected quaternary CaO-MgO-Al_2O_3-SiO_2 slag system were measured with sixteen different slag compositions based on different levels of CaO /SiO_2 ratio and MgO content at fixed Al_2O_3 value. The Al_2O_3 content was equalled to 30 mass%, the CaO/SiO_2 ratio was varied from 1.1 to 1.4 and MgO from 6 to 12%. The characteristic temperatures of the present investigation and the calculated values are presented in the Table 2. It is obvious that basicity and the MgO content had obvious influence on the characteristic temperatures of the selected slag. Depending on the relative significance of the predictors (CaO/SiO_2, MgO and Al_2O_3), the individual responses are found out using regression analysis based on the statistical approach are as follows:

$$ST = 1081 - 6.80 M + 311 R$$

$$HT = 1139 - 4.41 + 272 R$$

$$FT = 1158 + 1.49 M + 252 R$$

ST= Softening temperature

HT= Hemispherical temperature

FT=Flow temperature

The experimentally observed and calculated values by statistical model based on empirical of all the three responses for all the sixteen slag are presented in Table 2. It shows that the calculated values of ST differ from the observed values within the range of 4 to -5.Similarly, the difference between the calculated and the observed values of HT falls in the range of -3 to 7. As FT is concerned the difference between the observed values and the calculated values are in the range of -2 to 7.

Table 4.2 Composition of slag and the present results compared with estimation from empirical equations.

SI.No.	Analysed composition			Experimental calculation			Empirical calculation		
	Al_2O_3 wt. %	CaO/SiO_2	MgO wt. %	ST ^oC	HT ^oC	FT ^oC	ST ^oC	HT ^oC	FT ^oC
1	30	1.1	6	1378	1404	1437	1382	1411	1444
2	30	1.1	8	1368	1400	1445	1368	1402	1447
3	30	1.1	10	1358	1397	1452	1355	1394	1450
4	30	1.1	12	1347	1393	1460	1341	1385	1453
5	30	1.2	6	1413	1436	1467	1413	1438	1469
6	30	1.2	8	1401	1429	1472	1399	1430	1472
7	30	1.2	10	1388	1422	1476	1386	1421	1475
8	30	1.2	12	1375	1415	1481	1372	1412	1478
9	30	1.3	6	1447	1469	1497	1444	1466	1494
10	30	1.3	8	1433	1458	1498	1430	1457	1497
11	30	1.3	10	1418	1447	1500	1417	1448	1500
12	30	1.3	12	1403	1437	1501	1403	1439	1503
13	30	1.4	6	1481	1501	1527	1475	1493	1519
14	30	1.4	8	1465	1487	1525	1462	1484	1522
15	30	1.4	10	1448	1473	1523	1448	1475	1525
16	30	1.4	12	1431	1459	1522	1434	1466	1528

4.1.2 Effect of MgO on ST, HT, FT

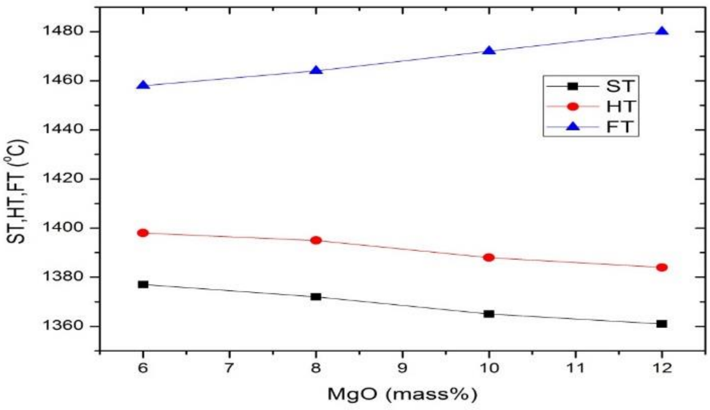


Fig. 4.1 Effect of MgO on ST, HT, FT

The Effect of MgO substance in the diverse characteristics temperature of manufactured high alumina blast furnace slag has demonstrating in the above chart. The above diagram indicating as MgO substance builds (6-12 mass %) the ST (softening temperature) declines, and HT (fluids temperature) likewise diminishes, yet FT (dissolving temperature) increments. So the outcomes demonstrates that for high alumina blast furnace slag (Al_2O_3=30 mass %, MgO=6-12 mass %) ST (softening temperature) and HT (fluids temperature) happens at higher temperature range.

4.1.3 Effect of C/S on ST, HT, FT

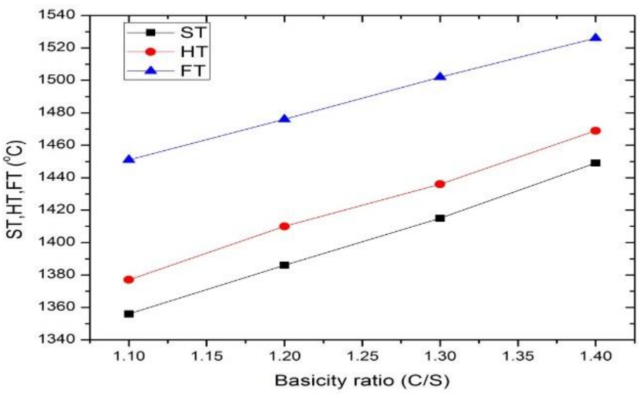


Fig. 4.2 Effect of basicity on ST, HT, FT

The Effect of C/S (basicity) content in the distinctive characteristics temperature of manufactured high alumina impact heater slag has demonstrating in the above diagram. The above diagram demonstrating as C/S (basicity) substance builds (1.1-1.4) the ST (softening temperature) increments, and HT (fluids temperature increments, and FT (dissolving temperature) likewise increments. So the outcomes shows that for high alumina impact heater slag (Al_2O_3=30 mass %, C/S=1.1-1.4) ST (softening temperature) and HT (fluids temperature) happens at higher temperature range.

4.1.4 Effect of MgO vs FT-ST

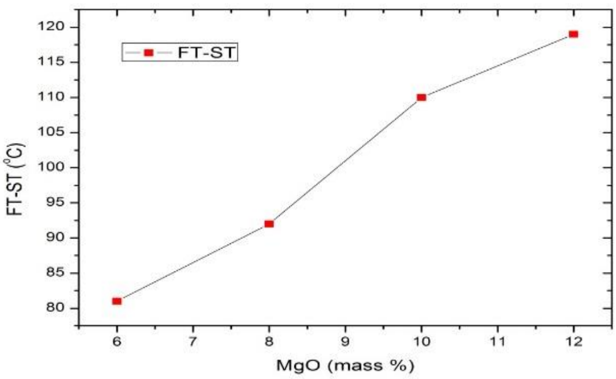


Fig. 4.3 Effect of MgO on FT-ST

The above figure representing that the MgO content increases as the different between FT-ST increases. The different between FT-ST showing the distance (thickness) between softening and melting behaviour of blast furnace slag. The softening-melting zone is also called cohesive zone of the blast furnace slag. So the different between softening and melting temperature of the blast furnace slag should be low for short slag. So low MgO content is beneficial for the formation of “Short Slag”, on blast furnace.

4.1.5 Effect of C/S vs FT-ST

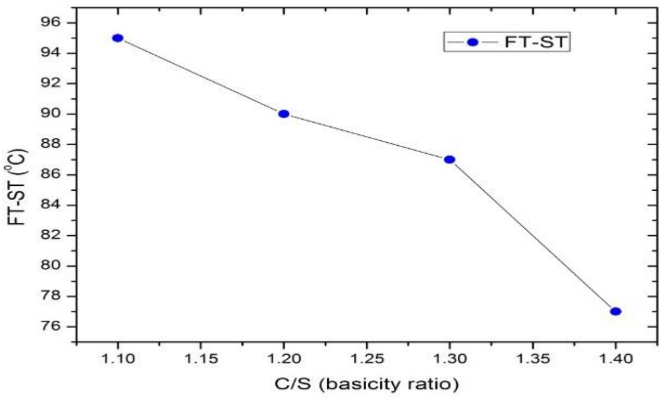


Fig. 4.4 Effect of basicity on FT-ST

With the increase in the C/S ratio the difference between FT and ST decreases. Under the range of composition examined a high C/S ratio is beneficial for the blast furnace process as it narrow the softening – melting range. It must be noted that from the process point of view the final slag should be a "Short Slag", a slag with a small different between the ST and FT. such a slag acquires liquids mobility and trickle down the furnace away from the site where it starts distorting plastically, as soon as possible. So high basicity ratio is beneficial for short slag.

4.2 High Alumina Slag Viscosity

The viscosities have measured at three pre-set temperatures. Viscosity of slag has measured by using iida model. Viscosities of different slag have presented in following tables.

Table 4.3 Viscosity (cpas) of slag at different temperatures;

Temperature	slag1	slag2	slag3	slag4	slag5	slag6	slag7	slag8
1623	54.32	53.90	52.05	50.67	49.27	48.09	47.19	46.26
1723	51.34	50.16	48.26	47.16	47.09	45.63	44.96	44.01
1823	40.96	39.12	38.17	37.86	38.57	37.28	36.19	35.86

Table 4.4 Viscosity (cpas) of slag at different temperatures;

Temperature	slag9	slag10	slag11	slag12	slag13	slag14	slag15	slag16
1623	45.96	44.12	43.96	43.01	42.86	41.73	40.15	40.04
1723	42.87	41.26	40.36	39.96	39.09	38.12	37.07	36.76
1823	34.26	33.87	32.76	32.02	31.96	30.68	29.32	29.03

The above tables showing the viscosity of slag at different temperature. Total 16 slag samples have taken at different compositions. In the measured values, showing that viscosity of slag is decreases as temperature increases.

4.2.1 Effect of MgO on Viscosity

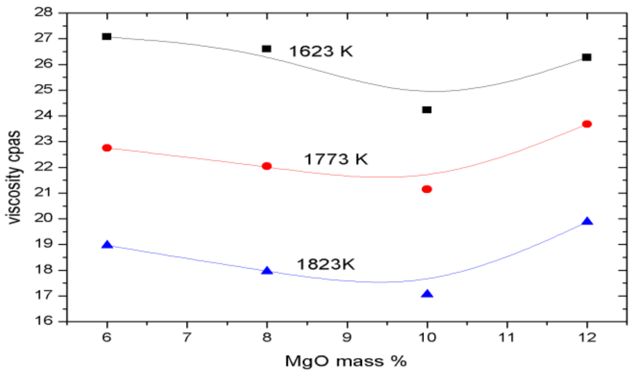


Fig. 4.5 Effect of MgO on Viscosity

However, the increase in MgO content of the slag decreases the slag viscosity; the deviation in the slag viscosity is not much important. However, the reduction in slag viscosity by increase in MgO content is simply up to 12 mass percentages. MgO has oxygen supplier, which are network breaker, leads to decrease in the slag viscosity.

4.2.2 Effect of C/S on Viscosity

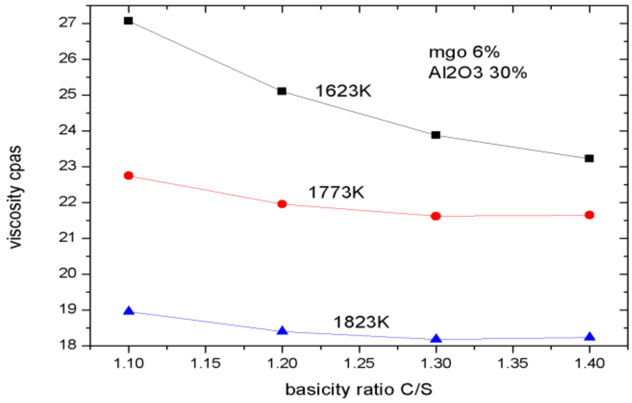


Fig. 4.6 Effect of viscosity on basicity ratio

The basicity ratio critically affects the slag viscosity. The chart clearly shows a declining movement with the increase in C/S ratio. This is since, with the increase in C/S ratio, the CaO and MgO increases and it acts as a network breaker. It breaks the silica tetrahedron and makes the flow stress-free, therefore decreasing the viscosity. The silicate structure changes from network to discrete anionic groups in the form of simple chains or rings. Basicity ratio is a ratio of basic oxides to acidic oxides, so basic oxides have an oxygen supplier, which breaks the silicon network and leads to decreases the viscosity of slag.

4.2.3 Effect of Viscosity on Temperature

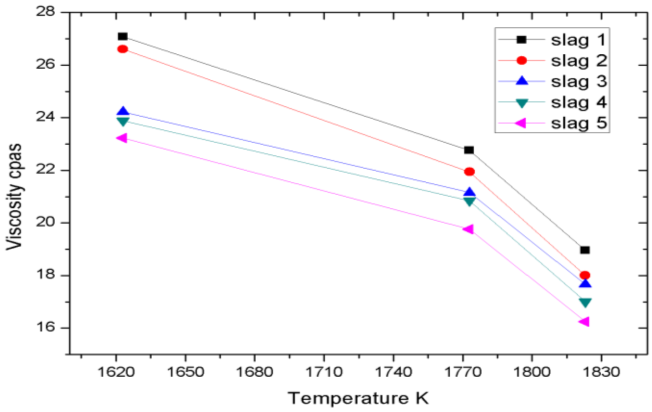


Fig. 4.7 Effect of viscosity on temperature

The above figure shows that the viscosity of slag decreases when temperature has increases. The viscosity of a slag is structure arranged. The viscosity of blast furnace slag is influenced by the system breaking cations like Ca^{2+}, Mg^{2+} and the level of polymerization of the silicate system. As clarified by Lee et al. [40] CaO and MgO, the fundamental monoxides bring down the viscosity by destructing the silicate system i.e, by depolymerizing while SiO_2 and Al_2O_3, which are exceptionally covalent oxides add to the increment of the slag viscosity . In this manner it is normal that increment of C/S proportion ought to abatement the slag viscosity at all levels. On the other hand, itemized examination would uncover the accompanying:

(i) Al_2O_3 in the silicate melts can act both as a system previous and a system modifier relying upon the measure of different oxides present. At the point when adequate fundamental oxide is available in the melt, i.e., when adequate oxygen is accessible in the melt, Al embraces a four-fold co-ordination with oxygen. In this case the melt would contain AlO_4^{5-} and SiO_4^{4-} ions.In this situation polymeric ions like

$$\begin{array}{ccccccccc} & O & & O & & O & & O & \\ & | & & | & & | & & | & \\ \{O- & Si & -O- & Si & -O\}\text{ and }\{O- & Al & -O- & Al & -O\} \\ & | & & | & & | & & | & \\ & O & & O & & O & & O & \end{array}$$

will be present in the melt to a higher extent, contributing towards the increase of the viscosity.

(ii) On the other hand when the amount of basic oxides like CaO and MgO is less, i.e., when sufficient oxygen is not available in the melt, Al would assume a six fold co-ordination (AlO_6). Here these AlO_6 groups would enter the interstices in the structure and cause depolymerisation reducing the percent of polymeric ions presented above and would contribute to the decrease of the slag viscosity.

The above clarifies the diminishing of the viscosity with increment of C/S proportion at lower levels of MgO. This is on the grounds that here the CaO and MgO blend would be low, lower degrees of oxygen would be accessible in the melt. Al would receive six-fold co-appointment and result in lessening of slag viscosity breaking down the structure into littler anionic units. The converse is likewise genuine. At the point when C/S proportion is expanded at larger amounts of MgO the CaO, MgO blend would be high, hico-appointment and the polymeric particles would be accessible in higher degrees in the melt, expanding the viscosity of the slag. Here, high and low M implies MgO is 12 and 6 wt % respectively.

4.3 X-Ray Diffraction

In the present investigation all the synthetic slag prepared in the laboratory are in granulated state. Out of these slag, 2 slag have been selected for phase analysison the basis of CaO/SiO_2 ratio & MgO content.

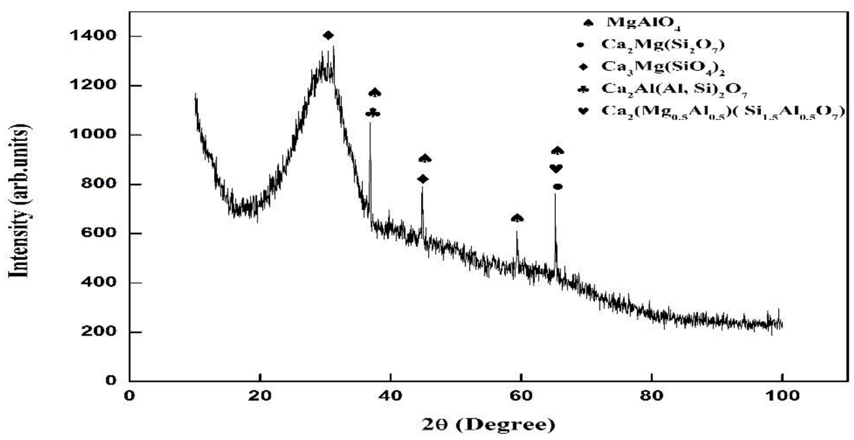


Fig. 4.8 XRD of cristallized slag 1

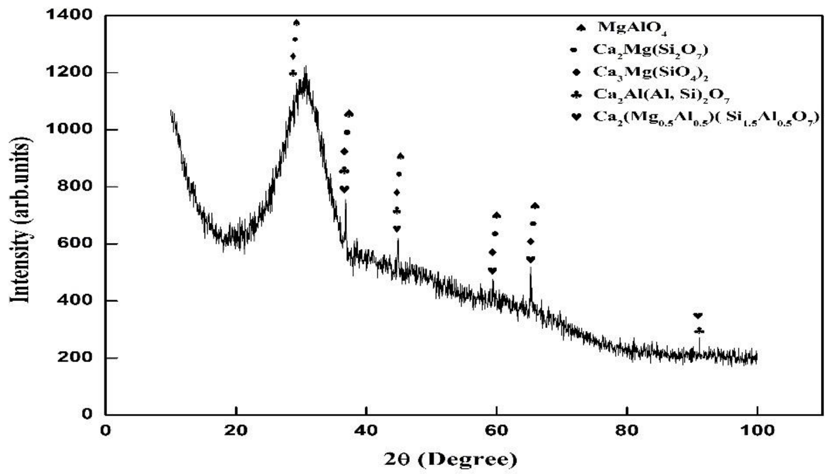


Fig. 4.9 XRD of cristallized slag 2

Table 9 Phases of Crystallized slag are given below

$Ca_3Mg(SiO_4)_2$	merwinite
$Ca_2Mg(Si_2O_7)$	Akermanite
$Ca_2Al(Al,Si)_2O_7$	Gehlenite
$Ca_2(Mg_{0.5}Al_{0.5})$ $(Si_{1.5}Al_{0.5}O_7)$	Melilite
$MgAlo_4$	Spinel

4.4 Conclusions

Flow characteristics of high alumina slag

- As thehigh Al_2O_3 content an increasing trend is observed in both softening and melting temperatures, this indicates that the formation of cohesive zone takes place relatively at high temperature, whereas the lower in flow temperature indicates the width of the cohesive zone.
- The increase in the MgO content decreases both softening and liquidus temperatures, where as the melting temperature increases with increase in MgO content.
- he difference between FT and ST increases as MgO content increases, which indicates a low amount of MgO is favourable to generate a short slag with in the range of composition.
- with the increase in the C/S ratio the difference between FT and ST decreases. Under the range of composition examined a high C/S ratio is beneficial for the blast furnace process as it narrow the softening – melting range.

- Under the range of compositions examined a high Al_2O_3 (30%) and high C/S ratio (1.4%) coupled with low MgO (4%) content is beneficial for the blast furnace process as it ensures the formation of a Short Slag.

Viscosity of high alumina slag

- The rise of temperature and C/S are inverse function of bringing down the viscosity of slag. So temperature increase being more effective in bringing down the slag viscosity at lower C/S ratio.
- Similar observation holds good for MgO variation, the ability to depolymerise the discrete silicate network is lower than that of CaO.
- Higher MgO content (above 10wt% MgO) don't participate in stoichiometric slag structure.

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